5.4 - IMPACT OF A SNOW PHYSICS PARAMETERIZATION ON SHORT-RANGE FORECASTS OF SKIN TEMPERATURE IN MAPS/RUC

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1. INTRODUCTION

A snow physics parameterization and snow cycling component has been added to the soil/vegetation scheme (Smirnova et al., 1997b) previously incorporated into the forecast component of MAPS (Mesoscale Analysis and Prediction System, Benjamin *et al*. 1996, 1997). (MAPS is implemented at the National Centers for Environmental Prediction (NCEP) as the Rapid Update Cycle or RUC.) The snow physics package accounts for the processes of snow accumulation on the ground surface and snow melting. Our goal here is to improve MAPS/RUC prediction of skin temperature and surface air temperature, and avoid the significant errors which may result even at short time scales from inaccurate forecasts of snow cover. The snow model, its testing in a 1-D framework, and implementation in the 3-D forecast scheme are discussed in the paper.

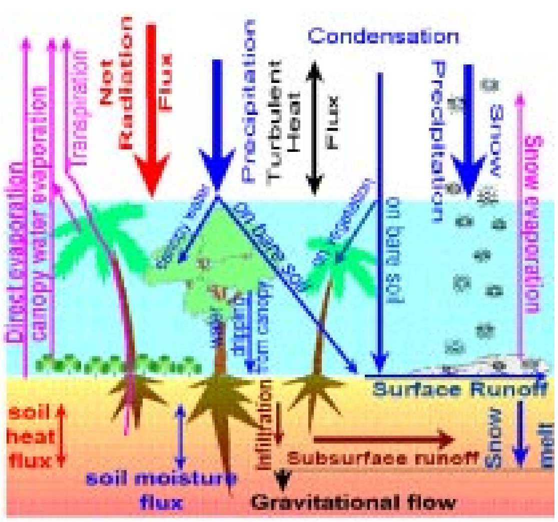

Figure.1 A summary of the processes in the MAPS/RUC soil/snow/vegetation scheme.

2. SNOW MODEL DESCRIPTION

The MAPS/RUC soil model contains heat and moisture transfer equations together with the energy and moisture budget equations for the ground surface, and uses an implicit scheme for the computation of the surface fluxes. The heat and moisture budgets are applied to a thin layer spanning the ground surface and including both the soil and the atmosphere with corresponding heat capacities and densities (Fig. 1). A concept for treating the evapotranspiration process, developed by Pan and Mahrt (1987), is implemented in the MAPS/RUC soil/vegetation scheme.

In the presence of snow cover, snow is considered to be an additional upper layer of soil that interacts with the atmosphere, significantly affecting its characteristics. The properties of snow are quite different from those of soil. High values of albedo reduce the amount of absorbed solar radiation, and the small thermal diffusivity in snow reduces coupling with temperatures in the soil layers below. As a result, the skin temperature may be much cooler where there is snow cover. Further, the atmospheric stratification frequently becomes stable with inversions near the ground.

The snow model contains a heat-transfer equation within the snow layer together with the energy and moisture budget equations on the surface of the snow pack. This budget is applied to the entire snow layer if snow depth is less than a threshold value, currently set equal to 7.5 cm, or to the top 7.5 cm layer of snow if the snow pack is thicker. Snow evaporates at a potential rate unless the snow layer would all evaporate before the end of the time step. In this case the evaporation rate is reduced to that which would just evaporate all the existing snow during the current time step. Heat flux within the snow layer is calculated with a constant value of thermal conductivity of 0.25 W $m^{-1}K^{-1}$, the average of values for new and old snow (Table 11-3, Pielke 1984). Averaged values from the same source are used for specific heat capacity of snow (2090 J kg^{-1} K^{-1}) and snow density (290 kg m^{-3}). A heat budget is also calculated at

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the boundary between the snow pack and the soil, allowing melting from the bottom of the snow layer. Melting at the top or bottom of the snow layer occurs if energy budgets produce temperatures higher than the freezing temperature (0^{o} C). In this case the snow temperature is set equal to the freezing point, and the residual from the energy budget is spent on melting snow. Water from melting snow infiltrates into the soil, and if the infiltration rate exceeds the maximum possible value for the given soil type, then the excess water becomes surface runoff.

The accumulation of snow on the ground surface is provided by the microphysics algorithm of the MAPS/RUC forecast scheme (Reisner et al. 1997, Brown et al. 1998). It predicts the total amount of precipitation and also the distribution of precipitation between the solid and liquid phase. The subgrid-scale ("convective") parameterization scheme also contributes to the liquid precipitation. With or without snow cover, the liquid phase is infiltrated into the soil at a rate not exceeding maximum infiltration rate, and the excess goes into surface runoff. The solid phase in the form of snow or graupel is accumulated on the ground/snow surface and is unavailable for the soil until melting begins.

3. ONE-DIMENSIONAL EXPERIMENTS

The MAPS snow model was tested off-line in a one-dimensional (1-D) setting before incorporation into the MAPS/RUC forecast scheme. The data from six stations located in the different climatic regions of the former Soviet Union, provided by Adam Schlosser (pers. comm.) and described by Robock et al. (1995), are excellent for such testing. In these 1-D experiments, the model simulates moisture and heat transfers inside the soil, and interaction processes between the ground/snow surface and the atmosphere, including surface fluxes, snow accumulation, and snow melting, driven by atmospheric forcing for a six-year period (1978-1983). The datasets for all six stations have a 3-hour frequency, and are interpolated to 30-minute intervals. The first year of simulations is repeated until an equilibrium state is reached, when the result is no longer dependent on the initial conditions. The simulated surface temperature, soil moisture, and snow water equivalent are verified against the real data to evaluate the performance of the snow-melting algorithm.

Figure 2 depicts various observed and simulated variables over the 6-year period for Khabarovsk, located in a moist forest area of Russia. The model captures the main features in the seasonal variations of soil moisture and also demonstrates consistency with precipitation events and periods of active snow melting. The snow water equivalent also appears to be in good agreement with observations. There are two main seasonal spikes in the moisture available for infiltration into soil (Fig. 2a): the first is in spring when the snow is melting, and the second is in the fall and is related to the precipitation maximum at that time. The driest periods of the year are the end of summer and winter. Similar features can be traced in the soil moisture content of the top 1 m (Fig. 2b), where there is also generally good agreement between the model and observations. The exception is 1980, when observed soil moisture values in spring and fall far exceeded both field capacity and model simulations. The year 1980 also had an abnormally large seasonal variation of observed soil moisture in comparison to the other five years. We can only speculate that the uncertainty of determining soil hydraulic properties in the model and the disregard of variation with depth of soil properties such as porosity and density may play an important role in this extreme situation, and yet provide reasonable performance of the model in other situations.

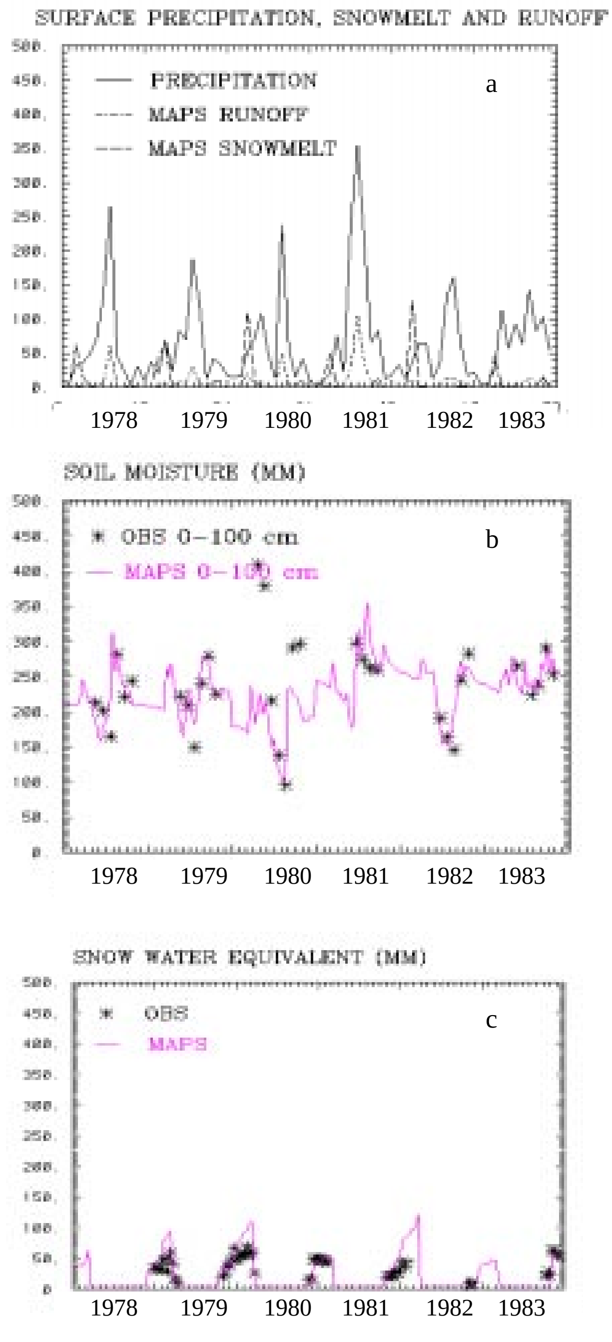

Figure 2. MAPS 1-D model results and observations from 1978-83 for Khabarovsk, Russia. a) Accumulation (mm) of observed precipitation and simulated runoff and snow melt; b) volumetric soil moisture in top 1 m of soil; and c) observed and simulated snow water equivalent over 10-day periods.

The performance of the MAPS/RUC soil/snow/vegetation scheme in dry climatic conditions is also tested. Data from Uralsk, located in the semiarid continental area of Kazakhstan, is appropriate for this purpose (Fig. 3 a,b,c). The small annual precipitation at Uralsk usually has a minimum during the warm season. The precipitation forcing in the 1-D experiments is the water equivalent of observed precipitation, and the 1-D model considers it to be snow if the atmospheric temperature is below freezing. This assumption works better for the regions with steady snow cover and low temperatures in winter. But, for Uralsk with its significant temperature variations, snow which in fact may fall at temperatures slightly above 0^{o}C might be incorrectly designated as rain. This could explain the underestimation of snow water equivalent (Fig. 3c). The snow melting process at this location takes place during the entire cold season (Fig. 3a), and not just in spring or early fall as at Khabarovsk (Fig. 2a). The simulated moisture volume in the top 1 m of soil has spikes in the cold seasons corresponding to the spikes of snow melt or precipitation (Fig. 3b). In most cases the response is adequate, although in January 1979 and December 1980 it is slightly overestimated. This behavior may be improved by taking into account frozen soil physics, which reduces moisture infiltration into frozen soil. In summertime, soil moisture content drops to the wilting point level as happens in reality, but changes corresponding to the summer precipitation events have less amplitude than the observed soil moisture.

Experiments were also conducted for four other stations, and overall the model demonstrated good performance of its snow-accumulating and snow-melting algorithms both in dry and wet climates. This off-line testing of the soil/snow/vegetation scheme was the basis for its incorporation into the 40km MAPS three-dimensional forecast scheme running in real time.

4. THREE-DIMENSIONAL APPLICATION

In April 1996, the multilevel soil/vegetation model was introduced into the continuously running MAPS assimilation system. The soil temperature and volumetric water content fields, as predicted by the soil model, have been allowed to evolve in the MAPS 3-hourly assimilation cycle over the 18 months (as of this writing) since that time. Because there is not yet a high-frequency, national domain precipitation analysis available in real time, it is necessary to depend on the MAPS 3-hourly precipitation forecasts for precipitation input. A description of the evolution of MAPS soil fields is presented by Smirnova et al. (1997; also available on-line at http://maps.fsl.noaa.gov/papers/smirnova/ams97_feb.newgif.html)

Since January 1997, a snow model with accumulation and melting processes and a full energy budget has been running in the real-time MAPS. This scheme was made possible by the addition in the same month of a relatively sophisticated cloud microphysics scheme (the level 4 scheme from the NCAR/Penn State MM5 research model, Reisner et al. 1997, Brown et al. 1998), allowing for the formation, transport and fallout of cloud water and cloud ice as well as rain, snow, graupel, and the number concentration of cloud ice particles. The scheme assumes an exponential distribution of precipitation particles and permits the coexistence at a grid point, if the temperature is between 0° and -40°C, of both water and ice hydrometeors. Along with the introduction of this scheme, a hydrometeor cycling capability has been added to MAPS, so that cloud fields from the previous 1-h forecast are used to initialize each new forecast, minimizing cloud spin-up.

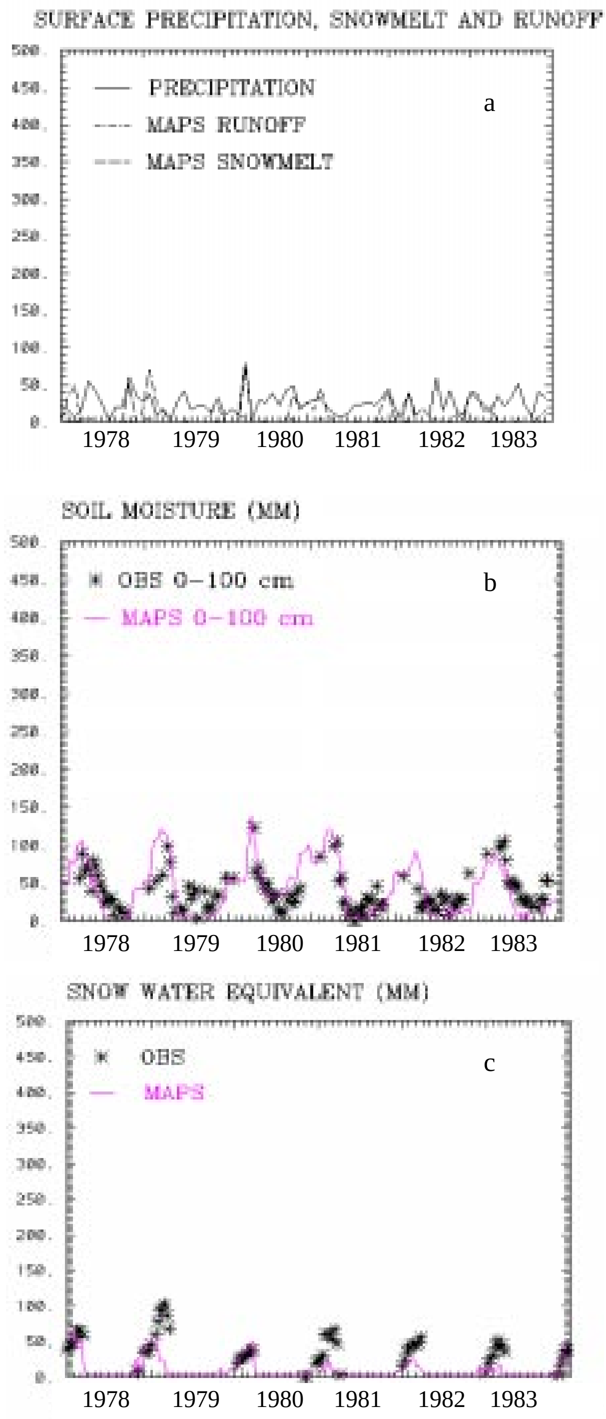

Figure 3. Same as Fig. 2 but for Uralsk, Kazakhstan.

From January through March 1997, the snow fields in MAPS were allowed to cycle over each 24-h period, with an update of the snow depth field occurring once daily from the USAF snow cover analysis. That analysis was a large improvement over using no snow cover at all, but has shown serious problems in certain situations such as continuous low cloud cover. Since early March 1997 through the end of May, the USAF analysis has been unavailable and, consequently, the snow cover field in MAPS has been allowed to cycle independently, as have the soil moisture and temperature fields. The results of this test (forced by external circumstances) have been very satisfactory, and suggest that, even with an improved snow analyses in the future, model forecast snow information should be combined with observation-based analyses to determine optimal snow fields.

Figures demonstrating the impact of snow physics parameterization on the forecast of skin and surface air temperature in the ongoing MAPS assimilation cycle will be presented at the meeting.

5. CONCLUDING REMARKS

Off-line one-dimensional testing of our soil/snow/vegetation scheme with snow accumulation and melting processes and a full energy budget has been undertaken on the data from several Russian stations. The model has demonstrated good performance in capturing the main features in seasonal changes of soil moisture and in the simulation of snow accumulation and snow melting. Further improvement of its results may be achieved by more accurate treatment of soil properties with the possibility of changing these properties with depth, by defining snow characteristics as a function of the snow age, and also by the incorporation of frozen soil physics into the current version of the scheme.

The soil/snow/vegetation model has a 9-month history (as of this writing) since its implementation into the ongoing 3-D MAPS cycle. Qualitative verification of soil moisture, snow accumulation, and snow melt fields shows that these fields, in general, are quite realistic. Further, low-level atmospheric temperature forecasts are generally improved in regions of snow cover, particularly in areas of recent snowfall or rapid melting.

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